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Impacts of vegetation and cold season processes on soil moisture and climate relationships over Eurasia

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[1] A number of modeling studies have addressed soil moisture persistence and its effects on the atmosphere. Such analyses are particularly valuable for seasonal to interannual prediction. In this study, we perform an observation-based study to further investigate the impacts of vegetation and cold season processes on soil moisture persistence and climate feedbacks. The joint analysis of independent meteorological, soil moisture and land cover measurements, without the use of a model, in the former Soviet Union provides a unique look at soil moisture–climate relationships at seasonal to interannual timescales. Averaged data over the growing season show a strong consistency between soil moisture and precipitation over grassland dominant regions, suggesting that precipitation anomalies are a dominant control of soil moisture at interannual timescales. Investigation of soil moisture persistence at the seasonal timescale shows a strong correlation between soil moisture in spring and the subsequent precipitation in summer over forest dominant regions and between cold season precipitation accumulation in winter and soil moisture in the following spring. Our findings can be explained by the theory proposed by Koster and Suarez (2001) and are consistent with the results from other modeling studies. Although it is hard to obtain the statistical meaningful conclusions because of the short data records, our results show the potential role of vegetation and cold season processes in land-atmosphere interactions. Further modeling studies and analyses using long in situ data records are necessary to fully verify our results.

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1. Introduction

[2] Land surface processes influence weather and climate by regulating the partitioning of surface water and energy exchanges. Soil moisture controls the relative magnitudes of the sensible and latent heat fluxes from the surface into the overlying atmospheric boundary layer, which can influence the atmospheric circulation. Soil has the ability to store precipitated water from periods of excess for later evaporation during periods of shortage and to "remember" the wet or dry weather conditions longer than atmospheric processes [*Shukla and Mintz*, 1982; *Koster and Suarez*, 2001]. Soil moisture stores exhibit persistence on the different timescales and varies with soil depth, geographical location, vegetation type, and climate [e.g., *Liu and Avissar*, 1999; *Wu and Dickinson*, 2004]. A 2–3 month soil moisture persistence exists in soil moisture measurements collected in Eurasia and Illinois, United States [*Vinnikov and Yeserkepova*, 1991; *Vinnikov et al.*, 1996; *Entin et al.*, 2000]. *Vinnikov and Yeserkepova* [1991] also found that the spatial variability of soil memory is also determined by prevailing atmosphere and surface conditions. Soil moisture memory ranges from less than a month at the surface to 4 1/2 months of memory at 1m depth in both mid- and high-latitude regions, with the opposite relationship in tropical regions due to the difference of solar radiation and the ratio of evaporation to precipitation [*Wu and Dickinson*, 2004].

[3] The persistence of soil moisture anomalies at seasonal to interannual timescales has a strong impact on the behavior of the atmosphere, according to atmospheric general circulation model studies [*Delworth and Manabe*, 1988; *Koster and Suarez*, 1995]. Understanding the control and the influence of soil moisture on regional climate may have implications for improving seasonal to interannual climate predictions, particularly for summer forecasts for transition zones between dry and humid regions [*Koster and Suarez*, 2001, 2003]. Soil moisture information may also be important not only for short-term weather forecasts, but also for predicting climate change, drought and flood disasters [e.g., *Yeh et al.*, 1984; *Pan et al.*, 1995].

[4] General circulation models (GCM) have been used to quantify the effects of soil moisture on future climate at both regional scales [*Pan et al.*, 1995; *Huang et al.*, 1996], and continental scales [*Yeh et al.*, 1984; *Mintz*, 1984;

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Koster and Suarez, 2001]. These models are particularly valuable tools to better understand the land-atmosphere feedbacks. However, different models with different parameterization schemes, produce different results. For example, some studies show the positive feedback of spring soil moisture and surface evaporation on summer precipitation [*Shukla and Mintz*, 1982; *Fennessy and Shukla*, 1999]. However, some studies show a negative feedback [*Giorgi and Marinucci*, 1996]. The Global Soil Moisture Data Bank [*Robock et al.*, 2000], an archive of historical soil moisture observations, allows these model results to be evaluated using direct observations of soil moisture and climate. The intensive soil moisture measurements collected at hundreds of Eurasian catchments, approximately every 10 days provide a baseline for evaluation of model performance, and potentially the improvement of model parameterizations [*Robock et al.*, 1995, 1998; *Schlosser et al.*, 1997; *Luo et al.*, 2003].

[5] Another approach to explore these land-atmosphere feedback processes is to analyze statistically the soil moisture variability from a multiyear integrated GCM model simulation [*Delworth and Manabe*, 1988; *Koster and Suarez*, 2001]. *Delworth and Manabe* [1988] first found that the soil acts as an integrator of the white noise spectrum (high frequency) of rainfall plus snowmelt input. The result is a red response spectrum (low frequency) of soil moisture, with temporal variability on both the intraseasonal and interannual scales. *Koster and Suarez* [2001] developed a more complex statistical model and demonstrated that soil moisture variability is not only controlled by atmospheric conditions (precipitation and radiation), but also by land surface processes (evaporation and runoff) and the feedback of soil moisture to consequent atmospheric conditions. However, these studies either neglect the roles of vegetation and cold season processes, which occur in the real climate system, or do not examine their roles explicitly.

[6] Cold land processes such as snow accumulation and melting processes play important roles in land – atmosphere interactions. Water is stored in snow during winter and released to the soil in spring after melting. In effect, snow stores water and builds up the soil moisture memory storage in spring. Soil memory behaves differently in regions with and without snow accumulation [*Wu and Dickinson*, 2004].

[7] Terrestrial vegetation influences climate and generally promotes the land/atmosphere water exchange via evapotranspiration and thus reduces surface temperature, but can also act to restrict surface transpiration when the vegetation is stressed [*Pielke et al.*, 1998]. Many studies demonstrated the role of vegetation in regional climate [*Dickinson and Henderson-Sellers*, 1988; *Xue et al.*, 2004; *Heck et al.*, 1999, 2001]. However, few studies have explored the role of vegetation on soil moisture memory and soil moisture–precipitation feedbacks.

[8] The purpose of this study is to analyze soil moisture and climate (precipitation and air temperature) feedbacks over Eurasia, particularly focusing on analyzing the roles of vegetation and cold season precipitation accumulation in soil moisture memory and soil moisture and precipitation feedbacks using independent meteorological, soil moisture and land cover measurements collected in the former Soviet Union. This study is based strictly on observational data; no model data are employed.

5. Summary and Discussion

[31] In this study we utilized independent measurements of soil moisture, monthly near-surface climate, and global land cover to investigate, without the use of a model, the relationships between soil moisture and near-surface climate at seasonal to interannual scales, emphasizing the influences of cold season processes and vegetation types on these relationships. At an interannual scale, a strong positive (negative) correlation between soil moisture and precipitation (temperature) is found over grassland. The correlations are weak over forest regions, because forests may remain moist enough (much greater mean soil moisture) that the trees are never water stressed. The immediate response between soil moisture and precipitation in grassland regions indicates that evaporation in grassland regions transfers water from near-surface soil to the atmosphere, whereas in forest regions, transpiration transfers water from deeper root zone soil to the atmosphere and reflects soil moisture memory with longer timescales [*Wu and Dickinson*, 2005].

[32] At the seasonal scale, accumulations of cold season precipitation are positively correlated with springtime soil moisture, then becoming negatively correlated in the summer. This result is consistent with *Meschcherskaya et al.* [1982], who used a longer observation period (27 years). This indicates that winter snow accumulation plays more important roles than the precipitation in spring because of snowmelting processes. The spring/summer autocorrelation of soil moisture is stronger for forests than for grassland, apparently because the greater loss of soil moisture during the growing season for grassland brings the soil moisture each year to approximately the same low limiting value. Our analysis in Russia is consistent with the idea that soil moisture anomalies can persist into summer, thereby enhancing precipitation in summer in forest dominant regions. This result can be explained by the theory proposed by *Koster and Suarez* [2001], that the residual of the combined precipitation, ET, and runoff acts to prolong the timescales of soil moisture memory over forest regions [*Mahanama and Koster*, 2005; *Wu and Dickinson*, 2004].

[33] The statistical analysis in this study is limited by the short data record, as the correlation is based on only eight data pairs. Monte Carlo analysis suggests that if no intrinsic, physical correlations between spring soil moisture and summer rainfall exist, a false positive correlation of 0.6 could still occur with a probability of about 6%. Inferring causality from the statistics is also dangerous, given that an external mechanism (e.g., persistent SSTs) may be responsible for the high correlation. However, our statistical analysis showed consistent results in many aspects. These are the relationship between soil moisture and precipitation at an interannual scale, and at a seasonal scale the relationship between winter snow accumulation and spring soil moisture and the relationship between spring soil moisture and summer precipitation. Moreover, our findings are consistent with the recent modeling studies [*Liu and Avissar*, 1999; *Wu and Dickinson*, 2004]. In this paper, we are careful in selecting Russia, a region away from monsoon influences as our study area, and we merely note that the statistics are consistent with it. Future modeling studies using longer in situ soil moisture time series is necessary to fully explore and verify these relationships.